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Common dateware mechatronic with resolver-to-digital converter

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Abstract

The evolution of mechatronics indicates that Technical Cybernetics (TC) was its progenitor, the parent science of informatics that at the present stage of human development has ensured the transition from an industrial to an information society, information (IT) and cognitive technologies (CT). However, we should recognize that the IT and CT, as catalysts for development and progress, represent only a shell, which acquires the substantive content when solving specific practical problems. In engineering practice, the MS act as such filling, defining the image of the technosphere of the 21st century [1]. A similar example is Common Dateware (CDW) [2] that translates the kinetic energy of an operating mechanism (OM) movement in mechatronics through the Resolvers-to-Digital Converters (RDC) [3], in which the output orthogonal signal resolvers are converted into an analog or digital equivalent of movement, realizing the connection between space and time [4].

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Keywords: Technical Cybernetics; Information and Cognitive Technologies; Mechatronics; Translating; Kind of Energy; Converting; Digital Equivalent of Displacement

1. Application areas and effectiveness of mechatronics

Outlining in 1954 a new paradigm forecast of TC N.Wiener drew attention to the fact that the computers will be actively used for direct control of the OM [5–7]. This required improving the electromechanics based on electronics, which led to the formation of the term «MECHATRONICS». It is a neologism of the words "Mechanics and Electronics", proposed by the Japanese engineer Tetsuro Moria in 1969.

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The term «MECHATRONICS» registered as a trademark in 1972 by Yaskawa Electronic (Japan), which is considered one of the world leaders in the development of contactless electric machines with permanent magnets (CMPM) [8]. S. Yaskawa confirms development effectiveness of mechatronics in the XX century, he said in the report "Future Trend in Intelligent Mechatronics Systems" at the Seventh Mechatronics Forum, Sept. 2000 in Atlanta, USA: **"This concept increased productivity in industries such as automotive, computers, communications equipment and enabled global development. This led to the efficiency of mass production. It was focused on material gain. Now we need to take at our disposal the concept of the environment - the full life cycle and "shake off the dust" – our business. As we move from the era of the "closed balanced society" to "open an unbalanced society", management and global standardization are required".**

These recommendations are relevant to the South Ural region, where it was possible to “shake off the dust” carefully and to give sufficient attention to the improvement of innovations aimed to improve the radiological situation. From this perspective, radiation-resistant MS for robotic vehicles for elimination of consequences of incidents and accidents at the nuclear industries (NI) are of interest [5, 6].

During relatively short existence of mechatronics it has penetrated all spheres of human activity. In industrialized countries mechatronics is a priority for the development of science and technology, determining the level of production, product competitiveness, quality of life, the defense capability and security of the nation. Mechatronics is a vivid example of the impressive results of interdisciplinary cooperation. Besides, mechatronics achievements have the greatest application in mechanical engineering and instrument making, machine tool construction and automotive industry, robotics, aerospace, medical, office and home appliances. The logo shown in Fig. 1a illustrates the application areas. MS for transport engineering and high-rise buildings lifts [9], which significantly increases energy efficiency by energy recovery during coasting, should be noted as the innovative applications.

The actual formation of mechatronics coincides with the withering in the 70s of the last century of TC and with the dawn in the 80's "informatics", which is a neologism of the words "information" and "automatics", introduced in France.

2. Structural Electronization of Mechatronics

Structure of Mechatronics can be presented in the form of the logo (Fig. 1b), reflecting its functions, taking into account the above neologisms, and corresponding the supplementing [4] definition: "**Mechatronics is a computer paradigm of TC, that provides the translating the energy type between mechanics and electronics by converting information through automation**".

The main feature of the MS structure is the presence of electromechanical (EMC) and automated information (AIC) components carrying, respectively, energy type converting and information forms conversion. Selecting CMPM justified not only by its broad functionality, but also its energy efficiency, contactless, controllability and the ability to eliminate gear which have been used in the electric drive (ED) for over 200 years. The presence of the gear in EMC prevents the establishment of precision MS due to backlash, which, according to the criterion of Miller, doubles the dynamic error. In practice, in continuous operation it is difficult to ensure the gear backlash less than 5′ due to wear gearwheels [7, 10].

Electronization, the consequence of which is to increase the effectiveness of the MS, achieved in gearless electricomechatronic system (GEMS), which implemented on the basis of CMPM. Its effectiveness, in turn, is largely dependent on the level and extent of dataware (DW), structural and algorithmic features of GEMS, which are determined by quantitative and qualitative indicators of the DW [11]. Therefore, the choice of the DW structure is an actual problem that typically contains primary measuring sensor (PMS), directly related to the OM and the CMPM rotor. In this respect the advanced design version of the EMC proposed by Danaher Motion and shown in cross section in Fig. 1c is a demonstrative variant [12]. The unit contains a CMPM, in which *resolvers* and clamping sleeve for interfacing with the OM are integrated.

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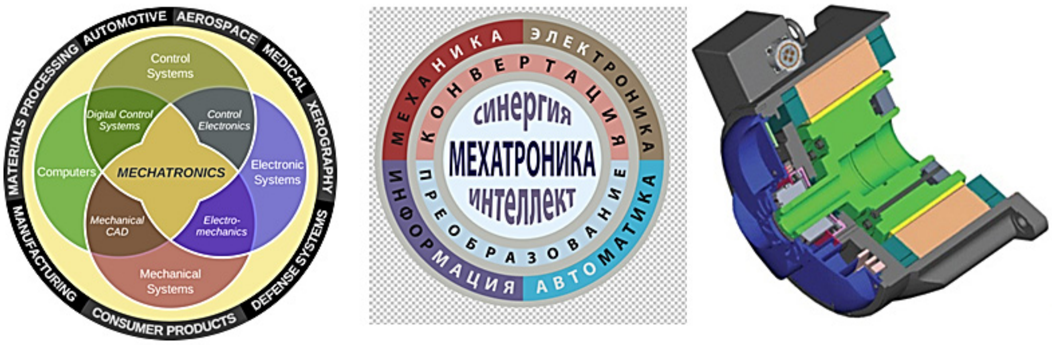

Fig. 1. (a) logo of mechatronics application arrears; (b) logo of Mechatronics; (c) EMC

3. Common Dateware of Mechatronic Systems

The equivalents of "authorized" $A_{s\Theta}$ and $A_{c\Theta}$ signals [8] determining the actual position of the rotor relative to its stator are needed for switching CMPM. For analog control the rotor position sensors (RPS) are used based on *reduktosin*, which is a kind of contactless *resolvers*, in which the number of pole pairs coincides with CMPM.

Restructuring MS, change of control algorithms of CMPM and transformation of displacement components occur as a result of evaluation by the ring transformer (RT) set and actual values of displacement components. Topical question is the question of choosing a device that provides an information exchange between EMC and AIC in MS having high functionality in terms of sustainability, accuracy and high-speed performance. The TC principles for this purpose provide the application of feedback loops [11], representing the analog or digital equivalent of displacement components. For their synthesis one can use special RDC [13], chips with an average degree of integration [14] and digital signal processors (DSP) in conjunction with the ADC and DAC. With the help of the DSP you can compensate the low-frequency drift, stray amplitude modulation and phase shifts of the convertible signals [8].

To suppress the quantization noise is advisable to use tracking converter *resolver* outputs [14], which are referred abroad RDC [3]. They are closed tracking systems with second order astatism, which is in the process of converting the output signals of *resolver* allows sequentially synthesize the analog equivalent of, respectively, the acceleration ε and velocity Ω by analog integration. Subsequent analog-to-digital integration allows synthesizing a digital value equivalent Φ_θ of displacement in absolute binary code which changes continuously. Self-organizing design of RDC [14] allows improving the dynamic indicates of conversion under rapidly changing inputs. This eliminates the main drawback inherent to foreign RDC analogues [3]. The recommendations set out in [15] help to improve utilization in mechatronics. High-speed ADCs are used to digitize analog equivalents of velocity Ω and acceleration ε. In the application for the conversion of the microcontroller (MC) digitization is performed by integrated ADC.

The operations necessary to form all components of the common dateware (CDW) to the MS with various embodiments of the PMS are shown in the table 1.

4. Common Dateware Primary Measuring Sensor

Among the PMS, based on the converting of electric power, dynamoelectric *resolvers* are most widely used. They are produced with windings on the stator and rotor. There are *resolvers* without windings toothed rotor (Fig. 2a), which is called the *vernernym resolver* [16] or *reduktosin*. Contactless *resolver* contains a ring transformer (RT) (Fig. 2b) for transmitting to the rotor excitation, which frequency is 0.4 ... 10 kHz. Contactless induction phase shifter type BIF are used (Fig. 2c) when operating at frequencies of 1.5 ... 350 kHz [13-15].

The practice uses of *resolvers* showed that the most effective in terms of improving the accuracy are two reporting PMS with mechanical (see. Fig. 2c) or rather with an electrical reduction. Its principle lies in the fact that for a small rotation angle of input axis PMS amplitude or phase of the output signal changes for one period, and when turning the rotor at 360^o the number of periods is equal to the velocity ratio of the electric reduction (VRER). Multi-pole *resolvers*, *reduktosins* and *inductosyns* are widespread in practice. The conversion error of the PMS is reduced by a factor equal to VRER. Furthermore, there is a weakening influence their technological and manufacturing errors, including irregularities in the air gap [14].

Table 1. Variants of CDW in MS with various PMS.

№ п/п	The type of primary measuring sensor	The displacement components on the PMS outputs	The operations necessary for the formation of the remaining components of the CDW
1	Coder	Position Gray $N_{\theta G}$ or Barker $N_{\theta B}$ code	Conversion to a binary code Φ_θ and double differentiation for getting Φ_Ω , Φ_ε; generation of $A_{S\Theta}$ and $A_{C\Theta}$ in the MC or DSP
2	Incremental sensor (IS)	Unitarian code N_θ, marker N_0 at $\theta = 0$	
3	Elektromashina sine-cosine resolver (ESCR)	Analog orthogonal displacement components $U_{S\theta}$ and $U_{C\theta}$	Conversion Φ_θ, Φ_Ω, Φ_ε , $A_{S\Theta}$ and $A_{C\Theta}$ by RDC and ADC
4	Optical absolute encoder (OAE)		Conversion Φ_θ, Φ_Ω, Φ_ε, $A_{S\Theta}$ and $A_{C\Theta}$ y ADC and DSP
5	The detector of the magnetic field (DMF)	Binary Codes Φ_θ, $\Phi_{S\theta}$ and $\Phi_{C\theta}$	Conversion $\Phi_{S\theta}$ and $\Phi_{C\theta}$ DAC in $U_{S\Theta}$, $U_{C\Theta}$, generation Φ_Ω, Φ_ε , $A_{S\Theta}$ and $A_{C\Theta}$ in DSP or MC

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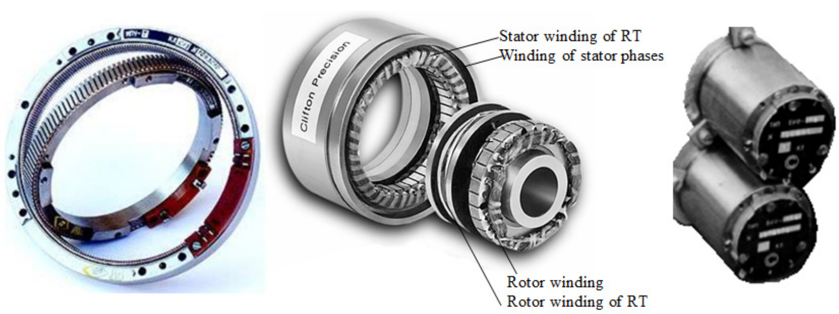

Fig. 2. (a) contactless r*eduktosin;* (b) *resolvers;* (c) *phase shifte*

Unlike *reduktosins* (see. Fig. 2a) from *resolvers* (see. Fig. 2b) is that both the primary and two phases of secondary windings located in the stator slots and the rotor is a gearwheel. The ratio between the numbers of teeth of the stator and rotor may be any. The main advantage of *reduktosin* is its contactless. At high rotor speeds of *reduktosin* it becomes possible to use its output signals, the amplitude of which depends on the rotor speed, for tachometry. However, the attenuation of the *reduktosin* output signal at more than multipolar *resolvers*, and in a small area of the stator slot can reach 40. Thus the slope of the tachometer signal is 1 mV/rpm that hinders the formation of a digital equivalent of velocity at low speeds of GEMS [11].

Electronization of PMS led to the creation *inductosyns* whose rotor and stator are discs of isolated (non-conductive) material, arranged coaxially and in parallel at a short distance from each other. Two primary multipole windings and one secondary winding are applied to the discs lithographically. The current powering with a frequency of 2 ... 20 kHz is produced by the method of pulsing or rotating field. The first mode is the amplitude, and the second is phase. Output signals not intended for broadcast over large distances [17].

All kinds of *resolvers* can determine the angle within one pole pitch. To increase the range of conversion one can use two samples or a device that allows you to record the number of pole pitches, fixing zero-crossing of accurate reading signal.

6. Application Features of the PD in Precision Mechatronics Systems

Precision MS requires using PMS with the error less than 20". Their maximum tracking speeds at a resolution of 16 bits reach 1000 rpm and the tracking error of ±2'+1 LSB, which corresponds to ± 7 LSB at a resolution of 16 bits. The most effective method of *resolver's* error compensation is the calibration that was used originally and in the first sample it is allowed to reduce the error from ± 50" up to ± 10" [17]. Over the past 60 years it is managed to bring the error to 1" [18]. The resolution 1.5" is attainable for RDC with electric reduction and 14-bit ADC under cyclic arctangent converting [13].

However, because of the PMS error high resolution of conversion does not provide high accuracy. Therefore, the implementation of precision GEMS used structural and algorithmic methods providing for increasing the resolution, repeatability and, in fact, accuracy [16]. As the RDC inferior absolute encoder in high-speed performance and accuracy, they can be used to check the error e_r , which is shown in Fig. 3a. Her character makes it possible to use the Fourier series. Fig. 3b shows the error curve, which decrease on the order after the injection of correction [8].

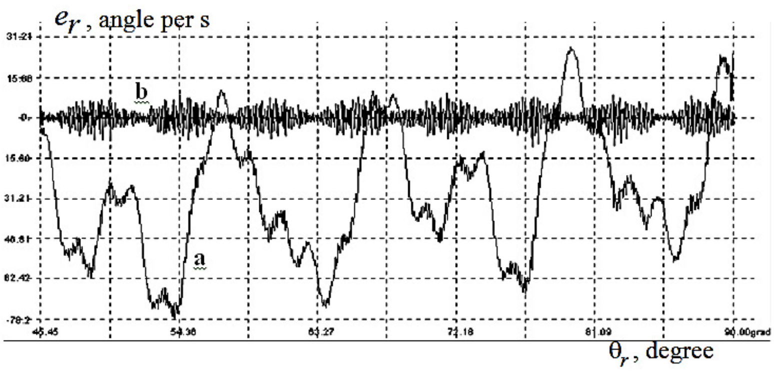

Fig. 3.(a) error curves before correction; (b) error curves after correction

7. Summary and Conclusions

Creating precision positioning devices, which began in the XX century [16], is obliged not to success in creating digital and discrete PMS. It is obliged to continuous improvement of *resolvers* that till now surpass coders and IS in terms of accuracy, resolution, high-speed performance, resistance to external factors, reliability, cost and efficiency of signal processing algorithms.

A common drawback of multi-pole *resolvers* and *reduktosins* is the difficulty of placing multiple windings that significantly increases the complexity of manufacturing contactless electromechanical PMS. They increased cost is not conducive to widespread use, but their use is justified by the need to obtain a long service life, high reliability and resistance to external influences.

There is an important ability of radiation-resistant *resolvers* to generate output two reporting signals, which parameters allow for interference-free transmission in the phase or amplitude modes, respectively, 3 or 5-wire cable interface from the EMC, located together with the OM in the area of increased radiation, to the distance providing reduction of radiation to values that allow the operation of microelectronics in the MEC. Digital information about the displacement components, formed in the AIC and necessary for controlling the energy converting, returns to the EMC through power circuits. This simplifies the robotization of vehicles operating at high levels of radiation [11].

Attempts to produce complete replacement *resolvers* code sensors did not give the desired effect because of the high cost of manufacturing the code sensors and complexities associated with the transfer of multi-bit digital equivalents of movement required to obtain components of the velocity and acceleration of operations of differentiation in digital processor with extremely high speed and noise immunity in MC.

The application of IS fit into the concept of using a serial interface. This version of the PMS not solved the problem of the dynamics and noise immunity of the formation of velocity and acceleration components. As a further disadvantage, it has a real possibility of data loss during transmission and lack of its self-healing after a power failure. "Sensorless" variants of dateware [19] accumulate these shortcomings of coders and IS. Getting information about the displacement with the help of indirect methods using models of electromechatronic converter can be carried out only approximately, because in most cases on the basis of modern microprocessor only simplified dynamic models of electromechatronic converter can be implemented [20].

High functionality and efficiency make *resolvers* and absolute encoders leaders of PMS mechatronics. They complement each other. The first exhibits higher rates of stability when operating in harsh operating conditions and the second has smaller error. The prospect of format of output orthogonal signals of RDC and OAE is confirmed by successful convergence of nanotechnology in mechatronics. The result of innovation was the emergence of DMF encoders having a space-time communication. Their orthogonal output signals are generated by the induction of the permanent magnet performing the functions of the PMS using Hall-effect or the anisotropic giant tunnel magnetoresonance. Unlike ESCR based on the principle of electro-mechanical energy conversion DMF do not require powering and they are general type sensors. They are not used in the phase format [21]. They do not apply the modulation-demodulation of signals.

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